2020

Comparison of Carbon Footprints: Mass Timer Buildings vs Steels – A Literature Review

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COMPARISON OF CARBON FOOTPRINTS: MASS TIMBER BUILDINGS VS STEEL – A LITERATURE REVIEW

by

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Source: Caulfield 2017.

Source: The Skyscraper Centre 2019.

FACULTY OF NATURAL RESOURCES MANAGEMENT

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

March 2020

COMPARISON OF CARBON FOOTPRINTS: MASS TIMBER BUILDINGS VS STEEL – A LITERATURE REVIEW

by

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An undergraduate thesis submitted in partial fulfilment of the requirements for the degree of Honours Bachelor of Science in Forestry

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March 23, 2020.

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ABSTRACT

Cooney, E. 2020. Comparison of Carbon Footprints: Mass Timer Buildings vs Steels – A Literature Review. 36pp.

Keywords: buildings, carbon footprint, climate change, concrete, engineered wood products, global warming, greenhouse gas emissions, mass timber, steel, sustainability

Sustainability and innovation are key components in the fight against climate change. Mass timber buildings have been gaining popularity due to the renewable nature of timber. Although research comparing mass timber buildings to more mainstream buildings such as steel is still in the early stages and therefore, limited. We are looking to determine the difference between carbon footprints of mass timber and traditional steel and concrete buildings. This is done with the intention of determining the sustainability and practicality of mass timber buildings.

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ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr. Mat Leitch for his assistance from picking a thesis topic, deciding relevant information to include and providing edits.

INTRODUCTION OF THE THESIS

The construction industry accounts for 30% of global GHG emissions (Crawford and Cadorel 2017; Mass Timber Institute n.d.a). As a society, we are in a critical period in which we understand the impact our actions have on the environment through scientific studies and the development of technology. The IPCC (2018) released a paper on the importance of limiting global warming to 1.5° C above pre-industrial levels. In this paper, it is estimated that human activities have caused approximately 1.0° C of warming already. The IPCC (2018) paper notes that limiting warming to 1.5° C is critical, as climate-related risks increase drastically after warming has passed this point. Reducing our greenhouse gas (GHG) emissions is the most significant thing we can do to reduce the effects of global warming. Our CO_2 emissions particularly are of significant concern; reaching and sustaining net zero global anthropogenic CO_2 emissions would halt anthropogenic global warming on large time scales (IPCC 2018). To reduce our global GHG, and more specifically carbon footprints the way we do things must change. For instance, the construction industry accounts for roughly 30% of global GHG emissions (Crawford and Cadorel 2017). As cities and their buildings have grown larger, concrete and steel have become the primary building materials, although these come with large environmental footprints. A study by Li et al (2018) noted that steel contributes 40-53% to global warming emissions and 40-80% of the total environmental emissions during construction. Additionally, cement production is responsible for 3% of global human-caused CO_2 emissions (Crawford and Cadorel 2017).

With construction GHG emissions making up such a large amount of global emissions, implementing sustainable and innovative building designs and materials is necessary. Conventional buildings are mainly made with steel which is the product of non-renewable resources. Steel can be produced using two main methods, both of which require an alloy to be made from coal and iron products (World Coal Association 2018). Mass timber buildings offer a potential solution to this problem. These buildings are typically made from cross-laminated timber (CLT), glue-laminated timber (Glulam), and laminated veneer lumber (LVL) (Crawford and Cadorel 2017). All of these are engineered wood products, often celebrated for the strength properties they possess. From an environmental point of view, mass timber buildings are an enticing alternative as they are a renewable forest product. Trees uptake CO_2 as they grow, turning this into energy and essentially locking this CO_2 inside. This CO_2 remains trapped until the tree degrades in some way, be it natural decomposition or fire. Thus, mass timber buildings will not only store the carbon sequestered from the forest the wood has come from, but more carbon will be sequestered by the regeneration of the forest following harvesting.

This leads to the focus of my research which is to review the literature to compare and contrast conventional steel buildings to mass timber buildings. These comparisons will cover strength properties, fire resistance capabilities, and the origin of raw materials. All leading to the research question: what are the carbon footprints of steel and mass timber buildings? With the expectation that mass timber buildings may have a near-neutral carbon footprint.

OBJECTIVE

The objective of this research is to analyze the literature to determine the carbon footprint of steel and mass timber buildings. This will provide further knowledge regarding future implications of developing sustainable mass timber buildings. Emphasis will also be placed on whether mass timber buildings are carbon neutral.

HYPOTHESIS

Mass timber buildings are a more sustainable option than conventional steel buildings because they have a lower carbon footprint.

LITERATURE REVIEW

CO_2 AND LIMITING THE EARTH'S WARMING TO 1.5^{O} C

The IPCC (2018) paper notes that limiting warming to 1.5° C is critical, as climate-related risks increase drastically after warming has passed this point. Reducing our greenhouse gas (GHG) emissions is the most significant thing we can do to reduce the effects of global warming. Our CO_2 emissions particularly are of significant concern; reaching and sustaining net zero global anthropogenic CO_2 emissions near 2050 would halt anthropogenic global warming on large time scales (IPCC 2018). Construction is an industry that has a large environmental impact and thus finding new, green building methods can play a significant role in the fight against climate change. Figure 1 below displays the atmospheric CO_2 in parts per million (ppm) since 2006. The data is taken from monthly measurements with the last measure from February 2020, at 413ppm CO_2.

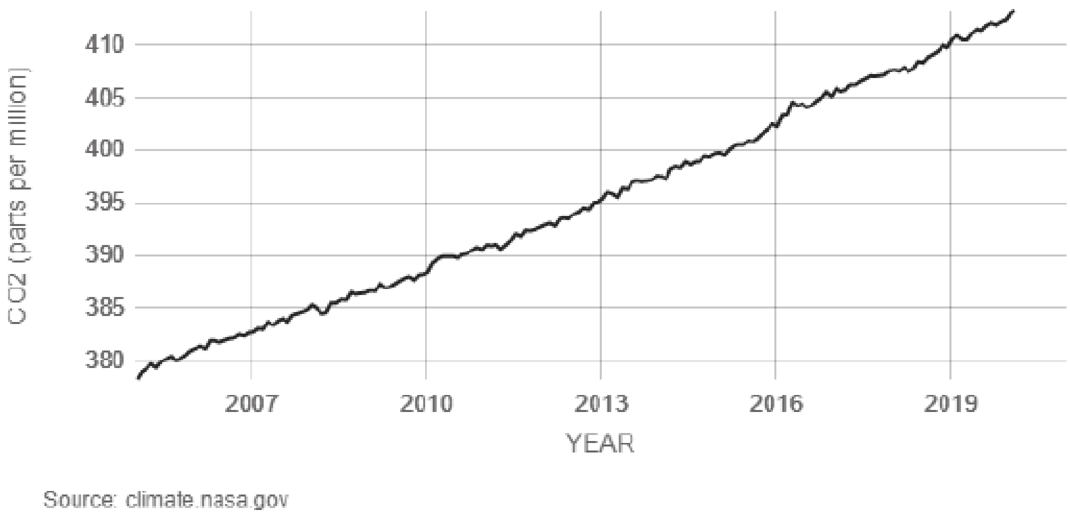

Figure 1. Monthly atmospheric CO_2 in ppm since 2006 (NASA 2020).

Figure 2 below displays another CO_2 trend with the data being a result of indirect measurements created by reconstructing ice core data. This graph helps to display the effect of anthropogenic CO_2 emissions by using CO_2 data from thousands of years ago.

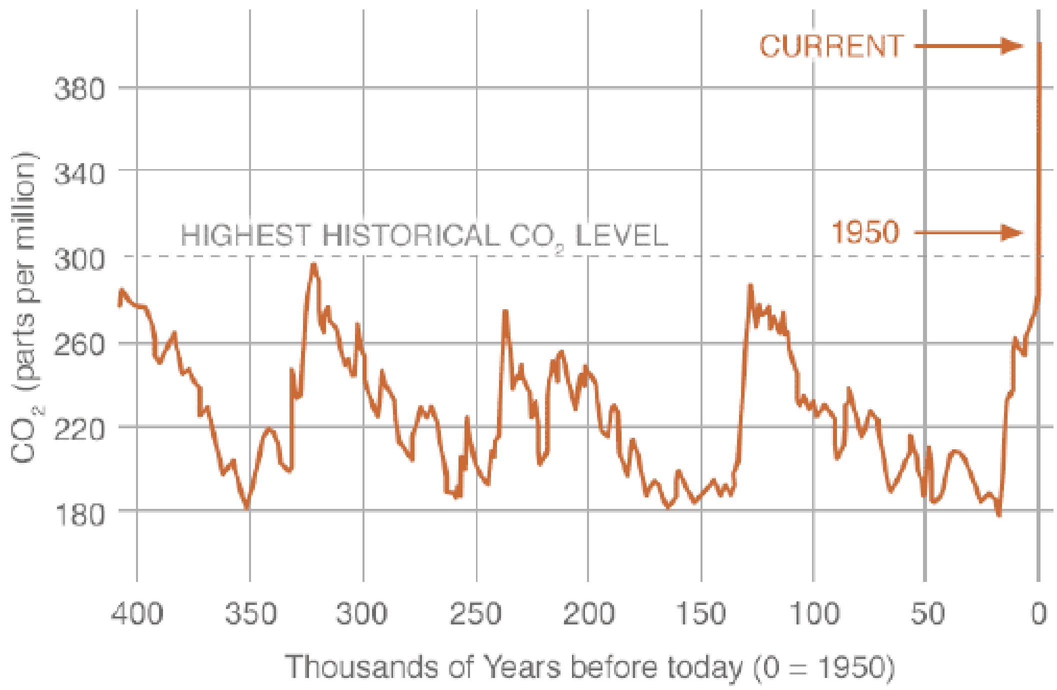

Figure 2. Graph displaying historic levels of atmospheric CO_2 in ppm and present day concentrations (NASA 2020).

HOW STEEL IS MADE

Conventional construction methods in Western countries use steel buildings with concrete foundations. Steel is an alloy that is primarily comprised of iron. Iron naturally occurs in the earth's crust as iron oxides; therefore, to be used to create steel there must be carbon added to create iron ore. The source of this carbon is coking coal, a process that drives out impurities, leaving almost pure carbon (World Coal Association 2018). Interestingly, Vancouver is both a leader in World coal exports, and in mass timber building development.

The steel alloy is produced using two main methods: basic oxygen furnace and electric arc furnaces. Other, less commonly used methods of steel production include pulverised coal injection and recycling. Basic oxygen furnace is the most commonly applied process for steelmaking, where iron is combined with varying amounts of steel scrap and small amounts of flux. 99% pure oxygen is then blown into the vessel via a lance; this causes the temperature to rise to 1700°C, melting the scrap metal and oxidizing present impurities while reducing the carbon content by 90%, resulting in the creation of liquid steel (World Coal Association 2018). Around 600kg of coke produces 1000kg of steel.

Electric arc furnaces do not involve iron making and reuse existing steel; essentially eliminating the requirement for raw materials and the processing of these materials. In some cases, it can include some direct reduced iron (DRI) or pig iron to achieve chemical balance. This method operates using an electrical charge between two electrodes which provides heat for the process (World Coal Association 2018). Power is supplied through the electrodes which are placed in the furnace to produce an arc of electricity throughout the scrap steel, raising the temperature to 1600°C to melt the scrap and remove impurities. Although they do not require coal as a raw material, many use it as a source of electricity generation. Figure 3 below provides an illustrated summary of the two main methods discussed above.

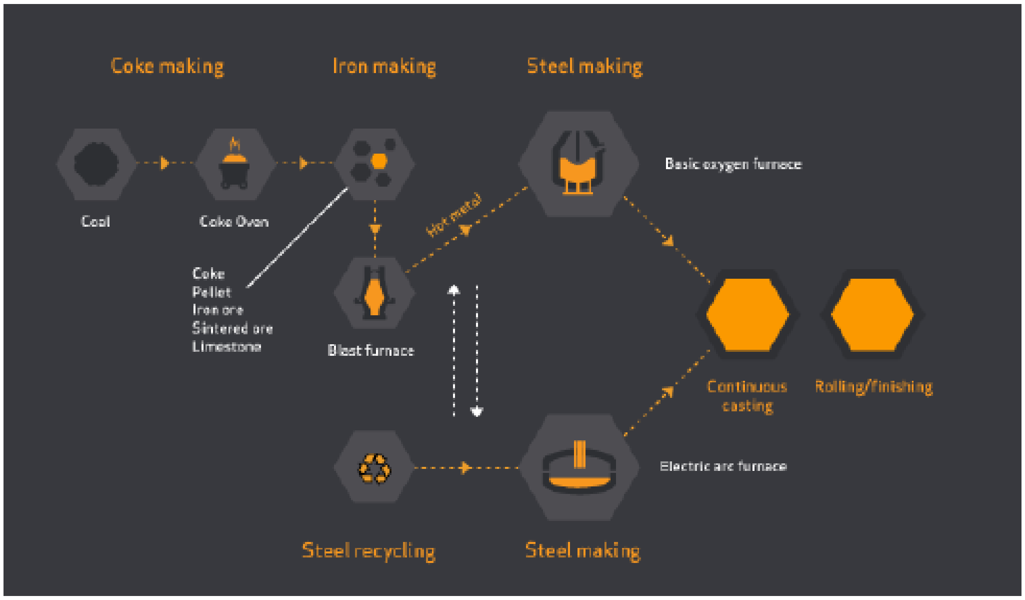

Figure 3. A summary of the steel-making process (World Coal Association 2018).

HOW MASS TIMBER BUILDINGS ARE MADE

Mass timber buildings on the other hand are made using engineered wood products. Similar to steel they are made using two main methods: a honeycomb system primarily comprised of cross-laminated timber (CLT), or as a post and beam type of construction using a mix of EWPs like CLT, glue-laminated timber (Glulam) and laminated veneer lumber (LVL) (Crawford and Cadorel 2017). The honeycomb system mentioned is often also referred to as light wood-frame, or CLT construction (reThink Wood n.d.). Other engineered wood products may be used as well, these three are the most common which we will focus on. Engineered wood products are created by fastening/bonding wood components together to create large, prefabricated building materials like walls, floors, beams, and roofs.

Mass timber buildings use off-site prefabricated materials for their construction. This leads to a decrease in material waste, and a decrease of on-site time and energy wasting as the building materials are ready once delivered to the site (Smith et al. 2018). These materials are then transported to the construction site for assembly, typically via trucks. Once at site, a crane and other machinery is typically used in combination with skilled wood installers. The University of British Columbia's Brock Commons building for instance used a crane to install the exterior glulam columns and a lifting device plus manual power to install the interior glulam columns. This building was constructed at a speed of two floors per week, resulting in the tallest mass timber building with a total potential carbon benefit of 2434 metric tonnes of CO_2 (naturally:wood 2016).

Mass timber buildings offer additional appeal as they are easily recyclable. Since EWPs use wood fragments, they can be ground down at the end of their life to create new EWPs. Or, previously used timber such as 2x4s or other materials can be ground down and recycled into EWPs to be used in mass timber construction (Kremer and Symmons 2015).

BACKGROUND INFORMATION ON CEMENT

Cement is made via a chemical combination of calcium, silicon, aluminum, iron, and other ingredients, and is thought to represent 5-7% of the total global anthropogenic CO_2 emissions (Hendricks et al. 1998; Chen et al. 2010). Some common ingredients used to make cement include limestone, shells, and chalk (Portland Cement Association 2019). Portland cement is used globally as the basic ingredient of concrete; this is the portion that creates a paste with water that will bind to the sand and rock before hardening.

Portland cement is most commonly made using a dry method in which raw materials such as limestone and clay are quarried and then crushed. The rocks are first crushed to a maximum size of 6 inches, and then crushed a second time to be reduced to < 3 inches (Portland Cement Association 2019). This crushed rock is then combined with other ingredients like iron ore and ash; ground, mixed, and then put into a cement kiln. The kilns may be up to 12 feet in diameter and are heated to 2700°F. During the kiln processes, some elements become gaseous; the remaining elements form "clinker" which are grey balls that come out of the kiln, roughly the size of marbles (Portland Cement Association 2019). The clinker is then cooled, ground, and mixed with gypsum and limestone. After this, the cement has completed the process of becoming ready-mix concrete.

MASS TIMBER BUILDINGS

A history

In the past wood was the building material of choice – construction using timber boards and panels was how most homes and buildings throughout cities in the United States were made. Unfortunately, buildings are less fire resistant than mass timber buildings that use engineered wood products. As a result, many fires devastated cities such as Chicago and Pittsburgh in the 1850s-1900s, leading insurance and construction companies to move away from wood and begin constructing with different materials such as concrete and steel. With climate change urging us to make more sustainable choices, mass timber is quickly gaining popularity and relevant research projects are on the rise.

Canada is the world leader in tall wood construction due to the maintenance of multi-disciplinary research in wood building systems and their collaboration with the national building code (NRCan 2018a). Despite this, in 2003 there was only one CLT manufacturer which was located in Europe and produced around 4000m^3 per year. This has now increased to around 50 CLT manufacturers globally with a combined production of about one million m^3 in 2017 (Crawford and Cadorel 2017). The past few years have seen many innovative solutions to building larger wood buildings, mainly through the use of mass timber construction. Some of which include the new development of engineered wood products like CLT, glulam, and LVL in the form of panels and beams which offer strength and safety properties previously unheard of with other, more conventional construction materials (NRCan 2018a).

In Canada, Natural Resources Canada (NRCan) has been funding the development of new generations of wood-based products, systems and structural solutions since 2007. In 2015 the Quebec government was the first in North America to officially support the construction of tall mass timber buildings, which are defined as wood buildings taller than 10 storeys. This was due to the release of the Directives and Explanatory Guide for Mass Timber Buildings of up to twelve Storeys. Investments such as these by NRCan also led to the 2015 edition of the National Building Code of Canada to adopt wood frame construction up to six stories (NRCan 2018a). British Columbia, Quebec, Ontario, Alberta, and Nova Scotia have amended their building codes to allow for mid-rise wood frame construction. These codes have resulted in over 500 mid-rise buildings being completed or under construction at the time of the NRCan (2018a) paper. Groups such as the Canadian Wood Council, FPInnovations, and the National Research Council are using the support from NRCan to reach a National Building Code of Canada target of reaching a national twelve storey wood building code, well beyond the current national six storey building code (NRCan 2018a).

Brock Commons

Brock Commons is a noteworthy mass timber building as it is currently the tallest in the world at 18 storeys. Of which, 17 storeys are of mass timber construction, atop of a one-storey concrete base with two full-height concrete cores (Forestry Innovation Investment 2020a). This building is estimated to have avoided and sequestered the equivalent CO_2 emissions of removing 511 cars off the road for a year (Forestry Innovation Investment 2020a).

The construction of Brock Commons used three Canadian mass timber products: CLT floor panels, glulam columns, and parallel strand lumber columns. These were all prefabricated which helped the build to proceed two months ahead of schedule (NRCan 2018b). The construction took about nine weeks with an average of two floors installed per week (Forestry Innovation Investment 2020b). The build was noteworthy as they had to adhere to certain standards and follow alternative means of consultation with the Authority Having Jurisdiction while proceeding with the build (reThink Wood n.d.) as buildings of this height were not considered in the building code at the time of construction.

What materials are used

Engineered wood products such as CLT, glulam, and LVL are commonly used. Other products commonly used alongside these include structural composite lumber (SCL), parallel strand lumber (PSL), dowel-laminated timer (DLT), nail-laminated timber (NLT), cross-nail laminated timber (CNLT) and interlocking cross-laminated timber (ILCT). These materials are prefabricated offsite into components such as columns, arches, floors, walls, and roofs before being shipped to the building (Smith et al. 2018). Concrete is also used in mass timber construction as a foundation, and sometimes used to support the structure with concrete floors or CLT topping slabs, such as in the case of the Brock Commons building (Edskar and Lidelow 2019).

Potential environmental impacts

It is well-known that improperly managed harvesting operations can result in a wide range of undesirable environmental impacts. These may include soil erosion or degradation, adverse impacts to riparian areas such as changed litter composition, bank erosion, and stability that may affect aquatic habitat (Lunn et al. 2017), and other environmental impacts. Fortunately, with proper forest management the environmental impacts can be reduced and mitigated while improving the forest. In addition to potential environmental impacts, forest operations have a carbon footprint of their own from the equipment used, vegetation decay, and soil disturbance (Winchester and Reilly 2020). Emissions from other aspects of mass timber construction must also be considered such as those associated with creating engineered wood products, pre-fabricating building components, and transporting materials to construction sites. Unfortunately, research thus far has had a major focus on solely analyzing the carbon emissions of harvesting activities and timber production (Winchester and Reilly 2020).

Structural integrity

With mass timber buildings gaining popularity as a sustainable option, architects and engineers alike are concerned about the buildings abilities to withstand disturbances. Much research has been conducted regarding the structural integrity of mass timber buildings to ensure they meet building code standards. Of particular interest is their response to high wind events, seismic activity, and fire resistance.

A study by Edskar and Lidelow (2019) examined two building types for mass timber construction: CLT and post-and-beam, and the response these buildings will have to high winds. They found the post-and-beam building type to be more useful in the construction of tall buildings as they exhibited stiffer behaviour and a higher tendency to bend than the CLT type that exhibited more shear behaviour. Mass timber buildings are noted to have high strength-to-weight ratios which makes it ideal for protection from seismic events (Caulfield 2017; reThink Wood n.d.; Smith et al. 2012). Following an earthquake February 22, 2011 in Canterbury, New Zealand, Smith et al. (2012) analyzed the effects of the seismic activity on a 95% complete, two-storey LVL building. The only component of the building lacking at the time of the earthquake was the spiral staircase and the railing around the opening of the second floor. The study found that there was no damage to the structure, the interior linings, or the exterior cladding. The researchers also noted the occurrence of aftershocks in June and December 2011, both of which resulted in no damage to the building. Another noteworthy building is the Albina Yard in Portland, Oregon which is designed for use in regions of high seismic activity. To address this, rocking mass timber shear walls were tested by the Network for Earthquake Engineering. These walls proved to be able to rock during seismic activity but return to a self-centred vertical position after seismic activity has seized (reThink Wood n.d.). Albina Yard was completed in 2018 and is the first building in the United States to use rocking mass timber walls as protection against seismic activity.

A study by Barber (2017) analyzed the fire resistance capabilities of glulam connectors, as these are a key component of a building maintaining its structural integrity following a fire. In this study, he notes that many authors state 300°C as being the temperature at which charring is complete. At this point, the char will act as an insulating barrier to the undamaged timber below (Barber 2017; Mass Timber Institute n.d.a). Therefore, charred portions of the wood can be scraped off and the timber below will maintain its mechanical properties. Bolts negatively affect the fire resistance of glulam connection compared to dowels. This is due to their heating capacity, and their ability to transfer more heat into the timber. This heat transfer results in timber stiffness (Barber 2017). This study states that the aspect of heat transfer may be the most important factor in ensuring that glulam or other wood connectors are able to maintain their integrity during and following a fire.

Regardless of Barber (2017)'s findings, CLT mass timber buildings exceeded the 2-hour fire rating required by building codes. A study conducted by the American Wood Council found that their experiment lasted 3 hours and 6 minutes when exposed to a standard fire reaching 1800°F in the first 90 minutes (reThink Wood n.d.). Similar studies were conducted by FPInnovations which again proved that CLT mass timber buildings would exceed the 2-hour fire rating standard by an hour. In this study, a stair/elevator shaft with two layers of gypsum protection showed no signs of smoke or heat penetration into the shaft after two hours and the structural integrity of the exit was maintained (reThink Wood n.d.).

ENGINEERED WOOD PRODUCTS (EWPS)

Cross-laminated timer (CLT)

CLT is a multi-layer mass timber product, with the layers spanning two directions. Some CLT such as CrossLam is labelled carbon negative due to the products being sourced from sustainably managed forests (Structurlam 2019). CLT is typically made into panels to be used for floors, walls, roofs, or cores of buildings. CLT is structurally comparable to steel and concrete but with a lighter weight. Additionally, due to the prefabrication of CLT panels they are more cost efficient and provide a reduced construction time (Structurlam 2019; Smith et al. 2016).

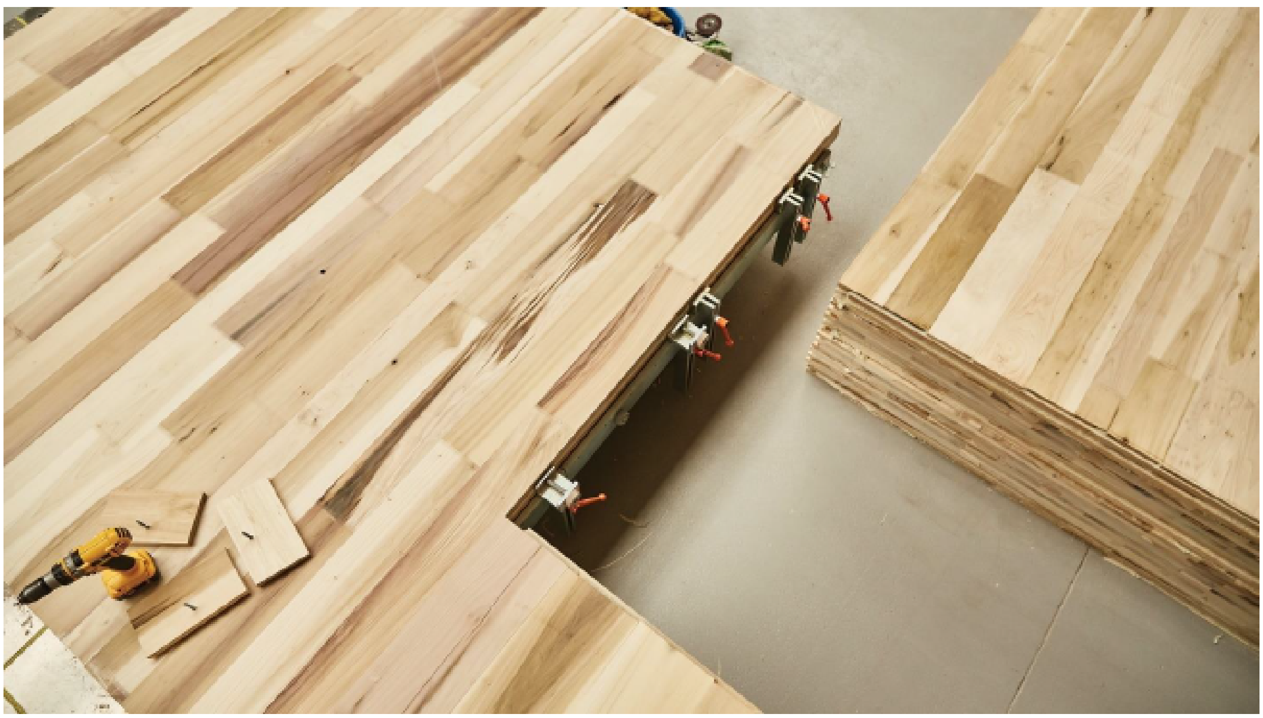

Figure 4. CLT panels clamped after being laminated (AHEC 2018).

Glue-laminated timber (glulam)

Glulam consists of multiple individual layers of dimensional lumber, which are glued together. All Canadian produced glulam is made using waterproof adhesives for the end joints and face bonding to suffice as exterior and interior wood (Canadian Wood Council 2019a). Glulam products are typically used in post and beam construction in heavy and mass timber structures and wood bridges. These wood products are typically used as headers, beams, girders, purlins, columns, heavy trusses, or curved members. The glulam products are often left exposed to contribute to the aesthetics of the building (Canadian Wood Council 2019a).

Figure 5. Curved glulam roof beams (Woodpecker Timber Framing 2017).

Laminated veneer lumber (LVL)

LVL is comparable in strength to solid timber, concrete, and steel. It is manufactured by bonding thin wood veneers under heat and pressure (Forest and Wood Products Australia Ltd.

2019). LVL is typically used for permanent structural applications including beams, roof trusses, framing, and portal frames; they are noted to be an ecologically sound choice. LVL trusses also use smaller dimension timbers over a longer distance, thus reducing total timber volume required in the roof trusses. Similar to other EWPs, prefabrication and the light weight of LVL materials allows for cost efficient and fast construction (Forest and Wood Products Australia Ltd. 2019).

Figure 6. LVL roof trusses (StructureCraft n.d.).

STEEL BUILDINGS

A history

In 1855, Sir Henry Bessemer created the Bessemer Method which made steel production more efficient. This method was further enhanced by Sidney Thomas as of 1879, who discovered how to remove phosphorous from steel which increased its quality. Due to these advances, by the 1880s steel quality became more consistent. Following a fire in Chicago, the city's Home Insurance Building completed in 1885 was the first 10 storey building to use steel as the frame. The light weight of this large building led to it becoming a more popular option. By the 1900s steel production technologies had increased so much that new steel was significantly stronger and thus became commonly used in railroads and buildings (Steel LLC 2018).

Potential environmental impacts

Coal mining results in significant CO_2 emissions among other environmental impacts. Some of which include surface structure diversion, destruction of ecosystems and biodiversity, land subsidence, soil erosion, and pollution often of the air and water (Hasanuzzaman et al. 2018). These environmental impacts affect society by exposing individuals to health issues such as those related to air and water pollution.

Structural integrity

Steel structures are known to exhibit severe damage following a fire although they typically do not collapse due to fire damage. Steel butt weld is one of the most common connectors used in steel construction. A study by Liu et al. (2017) found that the strength of steel butt welds was dependent on the materials used; some of the butt welds were not compromised until the temperature exceeded 600°C, whereas some were compromised after 400°C.

CARBON FOOTPRINTS

The carbon footprint of mass timber buildings and the EWPs they are made of can vary based on the harvesting and milling practices, making it difficult to determine an exact carbon footprint that is not on a case by case basis (Zeitz et al. 2019). Life cycle analyses of various engineered wood products have proven to be useful in determining the carbon footprints of these products. Many studies have attempted to collect data regarding the carbon footprint or global warming potential of engineered wood products and compared them to steel. Summarized below are some relevant findings.

Durlinger et al. (2013) conducted a lifecycle assessment of the CLT used in The Forté mass timber building in Australia and compared this to a reference building of a similar size and design made of concrete and steel. Many factors were considered in the assessment, including the emissions from creating the CLT materials and importing them from Austria. The emissions and global warming potential were also analyzed, both including and excluding carbon sequestration values. They found that including carbon sequestration, the Forté building had a 22% lower global warming potential than the reference building and still 13% less when excluding carbon sequestration. These values reflect the overall impact of the building including the impacts from construction and operation. Regarding carbon footprint of the CLT directly, Panel 1/m^2 and Panel 2/m^2 were noted to have net carbon footprints of -46 and -264 kg of CO_2 equivalent, respectively

(Durlinger et al. 2013). Thus, it can be drawn from this study that the CLT panels themselves have a carbon negative footprint in some cases. Additionally, the Mass Timber Institute (n.d.b) noted that 1m^3 of spruce pine fir (SPF) wood product equals approximately 1 tonne of carbon stored, and future recycling and reuse of the product will further carbon storage benefits. Unfortunately, determining the carbon footprint of the overall building is not as easy and there are many more factors involved. This means that although the building itself may not be carbon negative when all things are considered, it still exhibits greatly less emissions and global warming potential than a similar steel/concrete building as noted above.

Another study by Tellnes et al. (n.d.) was based on a six-storey housing development in Gothenburg Sweden. In this study, they found that mass timber buildings have roughly 35% lower GHG emissions than similar steel and concrete buildings. They also noted that the concrete foundation of mass timber buildings was responsible for almost half of the GHG emissions. Many other studies have been conducted analyzing the impact building with wood can have on reducing construction CO_2 emissions and how specific reduction goals can be achieved.

Oliver et al. (2014) states that global fossil fuel savings from wood construction could be between 12-15%. They additionally note that enough extra wood can be harvested sustainably and used in new building and bridge projects to reduce CO_2 emissions by 14-31%, and fossil fuel consumption by 12-19%. A study by Hildebrandt et al. (2017) found that simply using CLT and Glulam in new European residential buildings are likely to result in a carbon storage ranging between 29650-60500 kilotons of CO_2 equivalent. The highest values noted here would be reflected with a 24% increase of CLT usage and 12% Glulam in new developments.

Although Zeitz et al. (2019) noted that it is difficult to determine the exact carbon footprint of mass timber buildings due to the wide variety of factors involved, studies show similar results regarding the carbon footprint of mass timber buildings. Studies have found 14-35% less carbon emissions in mass timber buildings than steel/concrete (Oliver et al. 2014; Tellnes et al. n.d.) and 22% less global warming potential than steel/concrete buildings (Durlinger et al. 2013).

TRADITIONAL BUILDINGS VS MASS TIMBER BUILDINGS

Both building types have their pros and cons. Table 1 below summarizes some relevant pros and cons compared to traditional steel and concrete buildings to their mass timber counterparts.

Table 1. Summary of Traditional and Mass Timber Building Pros and Cons.

PROS	
Traditional Steel/Concrete Buildings	**Mass Timber Buildings**
Technology and local markets are already in place	Emissions reductions of CO_2 and other fossil fuels (Kremer and Symmons 2015; Durlinger et al. 2013; Oliver et al. 2014; Hildebrandt et al. 2017)

Table 1 (continued). Summary of Traditional and Mass Timber Building Pros and Cons.

PROS	
Traditional Steel/Concrete Buildings	**Mass Timber Buildings**
Commonly accepted building material	Lower construction times and safer construction sites (Smith et al. 2016; Kremer and Symmons 2015)
Current building codes are created with these materials having main consideration	Better thermal performance of building (Kremer and Symmons 2015; Mass Timber Institute n.d.b)
No need to find sustainable sources of raw materials such as wood	Increased fire resistance and charring potential to retain strength properties (Barber 2017; reThink Wood n.d.)
CONS	
High carbon emissions associated with construction (Crawford and Cadorel 2017; Li et al. 2018)	Minimal local markets and technologies in place, often increasing cost (Kremer and Symmons 2015)
Longer construction time results in a less safe construction environment (Kremer and Symmons 2015)	Many building codes do not yet include mass timber buildings, creating obstacles for architects and engineers (reThink Wood n.d.)

DISCUSSION

The time to find sustainable solutions to current building practices is now as the gap to limit global warming to 1.5° C is closing. Our current construction practices contribute 30% of global GHG emissions (Crawford and Cadorel 2017), additionally steel is responsible for 40-53% of global warming emissions (Li et al. 2018), and cement 3% of CO_2 emissions (Crawford ad Cadorel 2017). This research set out to address the hypothesis that: mass timber buildings are a more sustainable option than conventional steel buildings because they have a lower carbon footprint. Throughout the process, we have discovered that mass timber buildings are a suitable alternative to traditional steel and concrete building designs. Aside from their sustainable nature they offer other desirable properties. These include a high strength-to-weight ratio resulting in good performance during high wind events and seismic activity, and fire performance that exceeds building code expectations (reThink Wood n.d.). Additionally, following a fire charring of wood occurs and the structural integrity and strength of the wood would remain (Barber 2017; Mass Timber Institute n.d.a; reThink Wood n.d.). Mass timber buildings also offer faster on-site construction times which translates directly to a safer work site (Kremer and Symmons 2016; Smith et al. 2016). The overall construction cost of mass timber buildings is often similar to that of a steel/concrete building if you are not located near one of the few EWP manufacturers (Durlinger et al. 2013). Although, as the market changes and producers of EWPs become more wide-spread, mass timber buildings would become a much cheaper alternative than traditional buildings. Combined with these factors, mass timber buildings are a great candidate for the future of sustainable construction.

As mentioned previously, the construction industry and more specifically steel and cement use contribute greatly to global GHG emissions. We set out to determine whether mass timber buildings offer a lower carbon footprint than traditional steel and cement buildings, and imagined that mass timber buildings may even offer a carbon negative footprint. From analyzing the literature, it was noted that mass timber buildings have 14-35% less carbon emissions than traditional buildings (Oliver et al. 2014; Tellnes et al. n.d.) and 22% less global warming potential than steel/concrete buildings (Durlinger et al. 2013). The carbon footprint of CLT panels in The Forté mass timber building were noted to be negative with Panels 1 and 2 having -46 and -264 kg of CO_2 equivalent respectively (Durlinger et al. 2013). Research regarding the carbon footprint of mass timber buildings as a whole is lacking and difficult to determine as they vary extremely building by building. Multiple factors must be included when determining these carbon footprints such as the emissions from harvesting, manufacturing and prefabrication of EWPs, transporting the EWPs to site, and the construction process itself. This means that an exact carbon footprint cannot be determined for mass timber buildings and it must be on a case-by-case basis (Zeitz et al. 2019). Therefore, determining an average carbon footprint to place on mass timber buildings would be an ideal solution. This would require a large data set including the total carbon footprints of many mass timber buildings. Unfortunately, the research is not yet this extensive (Mass Timber Institute n.d.b) and we are currently left with the knowledge that mass timber buildings range from 14-35% less carbon emissions than traditional steel and concrete buildings. The type of foundation used greatly impacts the buildings carbon emissions as well, as noted by Tellnes et al. (n.d.) the concrete foundation made up half of their study building's GHG emissions.

With the knowledge that mass timber buildings have less GHG emissions and thus less global warming potential than traditional steel and concrete buildings, we can apply this to our current building practices in an attempt to meet IPCC goals of remaining below 1.5° C pre-industrial levels of atmospheric CO_2. This research demonstrates where the current literature is lacking. As noted above, more research is required to determine an average carbon footprint of mass timber buildings. Many factors contribute to the carbon footprint of a mass timber building, thus as of right now we know they have less emissions than a similar steel/concrete building. Further research could also dive into alternative types of foundation that may be more sustainable such as hemp concrete, because lowering the footprint of the foundation will drastically lower the overall footprint of the mass timber building.

CONCLUSION

Whether mass timber buildings have a carbon negative footprint and the exact value in general must be determined by future research. From the literature, we can conclude that mass timber buildings have a lower carbon footprint than traditional buildings, offer desired strength properties and an efficient construction process. Thus, they offer a more sustainable and efficient building option to address current issues surrounding climate change. As technology improves and research progresses, the suitability and sustainability of mass timber products and buildings will improve, furthering the positive benefits.

LITERATURE CITED

AHEC. 2018. Cross Laminated Collaboration. American Hardwood Export Council. https://www.americanhardwood.org/en/latest/blog/cross-laminated-collaboration. Mar. 22, 2020.

Barber, D. 2017. Determination of fire resistance ratings for glulam connectors within US high rise timber buildings. Fire Safety Journal. 91:579-585.

Canadian Wood Council 1. 2019. Glulam. Canadian Wood Council. https://cwc.ca/how-to-build-with-wood/wood-products/mass-timber/glulam/. Oct. 31, 2019.

Caulfield, J. 2017. Mass timber: from 'what the heck is that?' to 'wow!'. Building Design + Construction. https://www.bdcnetwork.com/mass-timber-what-heck-wow. Sept. 29, 2019.

Chen, C., G. Habert, Y. Bouzidi and A. Jullien. 2010. Environmental impact of cement production: detail of the different process and cement plant variability evaluation. Journal of Cleaner Production. 18:478-485.

Crawford, R.H., and X. Cadorel. 2017. A framework for assessing the environmental benefits of mass timber construction. Procedia Engineering 196:838-846.

Durlinger, B., E. Crossin, and J. Wong. 2013. Life Cycle Assessment of a cross laminated timber building. Forest & Wood Products Australia. www.fwpa.com.au. Mar. 5, 2020.

Edskar, I., and H. Lidelow. Dynamic properties of cross-laminated timber and timber truss building systems. Engineering Structures 186:525-535.

Forest and Wood Products Australia Ltd. 2018. Laminated Veneer Lumber (LVL). Wood Solutions. https://www.woodsolutions.com.au/wood-product-categories/laminated-veneer-lumber-lvl. Oct. 31, 2019.

Forestry Innovation Investment. 2020a. Introduction to Brock Commons – UBC Tall Wood Building. naturally:wood. https://www.naturallywood.com/resources/introduction-brock-commons-ubc-tall-wood-building. Mar. 17, 2020.

Forestry Innovation Investment. 2020b. Brock Commons Tallwood House – Chapter 3: Construction Process. naturally:wood. https://www.naturallywood.com/resources/brock-commons-tallwood-house-chapter-3-construction-process. Mar. 17, 2020.

Hasanuzzaman, Bhar, C., and V. Srivastava. 2018. Environmental capability: a Bradley-Terry model-based approach to examine the driving factors for sustainable coal-mining environment. Clean Technologies and Environmental Policy. 20:995-1016.

Hendricks, C.A., E. Worrell, L. Price, and N. Martin. 1998. Emissions reduction of greenhouse gases from the cement industry. Forest International Conference on Greenhouse Gas Control Technologies. In Interlaken, Austria, IEA GHG R&D Program.

Hildebrant, J., N. Hagemann, and D. Thrän. The contribution of wood-based construction materials for leveraging a low carbon building sector in Europe. Sustainable Cities and Society. 34:405-418.

IPCC. 2018. Global Warming of 1.5°C. Intergovernmental Panel on Climate Change. www.ipcc.ch Sept. 20, 2019.

Kremer, P.D., and M.A. Symmons. 2015. Mass timber construction as an alternative to concrete and steel in the Australia building industry: a PESTEL evaluation of the potential. International Wood Products Journal 6(3):138-147.

Liu, H., X. Lia, Z. Chen, and S.S. Huang. 2017. Post-fire residual mechanical properties of steel butt weld – experimental study. Journal of Constructional Steel Research. 129:156-162.

Li, H., Q. Deng, J. Zhang, B. Xia, and M. Skitmore. 2019. Assessing the life cycle CO_2 emissions of reinforced concrete structures: four cases from China. Jounral of Cleaner Production 210:1496-1506.

Lunn, T., S. Munks, and S. Carver. 2017. The impacts of timber harvesting on stream biota – an expanding field of heterogeneity. Biological Conservation. 213:154-166.

Mass Timber Institute. n.d.a. Fire and Mass Timber. The Future of Sustainability. https://static1.squarespace.com/static/5aba51381aef1d9309b04025/t/5d966bc33391767b8d18b85b/1570139076793/MassTimber%26Fire.pdf. Mar. 23, 2020.

Mass Timber Institute. n.d.b. Environment and Mass Timber. The Future of Sustainability. https://static1.squarespace.com/static/5aba51381aef1d9309b04025/t/5d966d0043940446e50c21b4/1570139394392/MassTimber%26Environment.pdf. Mar. 23, 2020.

NASA. 2020. Carbon Dioxide. NASA Global Climate Change. https://climate.nasa.gov/vital-signs/carbon-dioxide/. Mar. 21, 2020.

naturally:wood. 2016. Brock Commons Time Lapse – UBC Tall Wood Building. Video File. https://www.youtube.com/watch?v=GHtdnY_gnmE. Nov. 15, 2019.

NRCan. 2018a. Greening our built environments with wood. Natural Resources Canada. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/forest-industry-trade/forest-products-applications/greening-our-built-environments-wood/16834. Oct 31, 2019.

NRCan. 2018b. Tall wood building demonstration initiative (TWBDI). Natural Resources Canada. https://www.nrcan.gc.ca/science-data/funding-partnerships/funding-opportunities/forest-sector-funding-programs/expanding-market-opportunities-p/tall-wood-building-demonstration-initiative-twbdi/20176. Oct. 31, 2019.

Portland Cement Association. 2010. How cement is made. Portland Cement Association. https://www.cement.org/cement-concrete-applications/how-cement-is-made. Oct. 31, 2019.

reThink Wood. n.d. Mass Timber in North America. Educational-Advertisement. https://www.awc.org/pdf/education/des/ReThinkMag-DES610A-MassTimberinNorthAmerica-161031.pdf. Mar. 1, 2020.

Smith, R.E., G. Griffin, T. Rice, and B. Hagehofer-Daniell. 2018. Mass timber: evaluating construction performance. Architectural Engineering and Design Management 14:127-138.

Smith, T., D. Carradine, S. Pampanin, R. Ditommaso, and F.C. Ponzo. 2012. Seismic performance of a post-tensioned LVL building subjected to the Canterbury earthquake sequence. 2012 NZSEE Conference. http://db.nzsee.org.nz/2012/Paper126.pdf. Mar. 1, 2020.

Steel LLC. 2018. A brief history of steel construction. Steel LLC. https://www.steelincga.com/a-brief-history-of-steel-construction/. Oct. 31, 2019. https://www.structurlam.com/construction/products/d/cross-laminated-timber-clt/. Oct. 31, 2019.

StructureCraft. n.d. Laminated Veneer Lumber. StructureCraft. https://structurecraft.com/materials/engineered-wood/laminated-veneer-lumber. Mar. 22, 2020.

Structurlam. 2019. Cross laminated timber (CLT). Structurlam Mass Timber Corporation.

The Skyscraper Center. 2019. U.S. Steel Tower. The Skyscraper Center. http://www.skyscrapercenter.com/building/us-steel-tower/801. Sept. 29, 2019.

Winchester, N., J.M. Reilly. 2020. The economic emissions benefits of engineered wood products in a low-carbon future. Energy Economics 85:1-9.

Woodpecker Timber Framing. 2017. Glulam. Woodpecker Timber Framing. http://europeantimberframing.com/services/glulam/. Mar. 22, 2020.

World Coal Association. 2018. How is steel produced? World Coal Association. https://www.worldcoal.org/coal/uses-coal/how-steel-produced. Oct. 15, 2019.

Zeitz, A., C.T. Griffin, and P. Dusicka. 2019. Comparing the embodied carbon and energy of a mass timber structure system to typical steel and concrete alternatives for parking garages. Energy & Buildings 188:126-133